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BOWHEAD WHALE BEHAVIOR IN RELATION TO SEISMIC EXPLORATION, ALASKAN BEAUFORT SEA, AUTUMN 1981

by

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San Diego, CA 92152

for

U.S. Minerals Management Service[1]
12203 Sunrise Valley Dr.
Reston, VA 22091

October 1985

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REGISTERED

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BOWHEAD WHALE BEHAVIOR IN RELATION TO SEISMIC EXPLORATION, ALASKAN BEAUFORT SEA, AUTUMN 1981

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ABSTRACT

Behavior of bowhead whales in the eastern part of the Alaskan Beaufort Sea or near the Alaska/Yukon border was observed from a circling turbine-powered Goose aircraft on 10 dates from 12 September to 5 October 1981. On three of these dates, the whales were exposed to noise impulses from seismic vessels 13 km or more away. Observations were hampered by logistic complications, including low cloud ceilings on the majority of the days. However, some behavioral data were acquired.

In both the presence and the absence of seismic impulses, most bowheads appeared to be feeding in the water column, although slow travel and active socializing were sometimes detected. Sonobuoys detected bowhead calls both in the presence and the absence of seismic impulses. There was no clear evidence of unusual behavior in the presence of seismic impulses. However, on one date whales 13-19 km from an approaching seismic exploration vessel may have been slowly avoiding the vessel at the same time as they engaged in other seemingly-normal behaviors.

INTRODUCTION

Recently it has been perceived that underwater industrial sounds may have the potential to affect whales and other marine mammals adversely (Payne and Webb 1971; Geraci and St. Aubin 1980; Acoustical Society of America 1981; Richardson et al. 1983). This could, in theory, occur through the interrelated processes of disturbance, interference with communication, stress, or geographical displacement.

- Various kinds of offshore industrial activities have been shown to cause short-term disturbance to baleen whales, including bowhead whales (Richardson et al. 1983, 1985b,c).
- Increases in levels of continuous noise (e.g. ship noise) cause an inevitable reduction in the theoretical maximum range at which a whale can hear sounds from any source of interest (e.g. another whale). However, there is little information about the importance to whales of such sounds from distant sources.
- The possibility that industrial noise may stress baleen whales has not been studied.
- The possibility of long-term geographical displacement by industrial noise has been discussed widely, but it is very difficult to document whether observed changes in distribution of baleen whales are attributable to disturbance or to some other factor, such as variations in food supply or ice cover (Marine Mammal Commission 1979/80; Richardson et al. 1985a).

Concern has arisen that the endangered Western Arctic population of bowhead whales, Balaena mysticetus, might be affected by noise from offshore oil exploration and development in the Beaufort Sea and elsewhere in its range. In response to this concern, the U.S. Bureau of Land Management and U.S. Minerals Management Service have funded various studies. Since 1979, those agencies have funded the Naval Ocean Systems Center (NOSC) to conduct aerial surveys to document the distribution and movements of bowhead whales in Alaskan waters (Ljungblad et al. 1980, 1982a, 1983, 1984a, 1985a; Ljungblad 1981). During 1980-84, those agencies also funded LGL Ecological Research Associates to study the reactions of bowheads to actual and simulated industrial activities (Richardson [cd.] 1982, 1983, 1984, 1985). The latter study was done in the eastern (Canadian) portion of the Beaufort Sea rather than in Alaskan waters. The Canadian Beaufort Sea was chosen partly because of the relatively favorable study conditions (bowheads occur there during the summer open-water season), and partly because offshore oil exploration was further advanced in the Canadian than in the Alaskan Beaufort Sea.

One of the first major activities that the oil industry undertakes when exploring offshore is geophysical exploration (also known as seismic exploration). Extensive seismic exploration was underway in the Alaskan Beaufort Sea well before industry began to drill many exploratory wells there. Because seismic exploration involves creation of very intense underwater sounds (see below), there was concern that bowhead whales might be affected. For this reason, regulatory agencies concluded that an effort should be made to monitor the behavioral reactions, if any, of bowheads to seismic exploration in the Alaskan Beaufort Sea. This behavioral work was to be done along with the ongoing aerial survey effort in Alaskan waters and the more extensive behavioral study in the Canadian Beaufort Sea.

This report describes the 1981 component of the effort to monitor behavioral reactions of bowheads to seismic exploration in the Alaskan Beaufort Sea. Reeves et al. (1983, 1984) and Ljungblad et al. (1984b) have described the continuation and expansion of this work in 1982 and 1983. A report on the 1984 component of the work is in preparation.

Characteristics of Noise from Seismic Exploration

The most intense sounds that are normally introduced into the water by the activities of the petroleum industry come from seismic (geophysical) surveys. During such surveys, intense impulses of underwater sound are created. The echoes returning from interfaces between geological strata are recorded in order to provide information about geological structures below the sea floor. The sound impulses were formerly created by explosives, but in recent years non-explosive sources have been used for most seismic surveys in North American waters. During the open water season in the Beaufort Sea, the most commonly used sources are arrays of airguns towed behind seismic survey ships. A chamber in each airgun is filled with compressed air, and then all air guns in the array nearly simultaneously release the air into the water. This creates an intense and somewhat directed impulse of sound. Almost all of the energy is at frequencies below 500 Hz. The airgun array is fired every several seconds as the survey ship moves slowly forward.

The broadband source level of the noise impulse created by a typical airgun array is 245-250 dB with respect to 1 microPascal at a standardized distance of 1 m, hereafter abbreviated as dB//1 µPa-m (Johnston and Cain, in Richardson et al. 1983). In comparison, the broadband source levels of the continuous engine and propeller noise from the noisiest ships are roughly 200 dB//1 µPa-m. Most vessels have source levels lower than this (e.g. 180-190 dB//1 µPa-m). Background noise levels from waves, wind and most other natural sources are much lower -- typically around 100 dB//1 µPa (Greene 1982-85; Richardson et al. 1983).

Noise pulses from seismic vessels are often detectable as much as 50-100 km away (Ljungblad et al. 1980; Greene 1982-85; Malme et al. 1983; Reeves et al. 1983). Noise levels from seismic vessels decrease with increasing range from the seismic vessel, as does any underwater noise. The rate of attenuation depends on water depth and other factors that affect sound propagation. In the eastern Beaufort Sea, noise from seismic vessels is detectable farther away when the water is deep than when it is shallower (Greene 1983).

Two other factors that affect the received level of seismic noise are (1) aspect relative to the source, and (2) depth of the receiver. When the source of the noise pulses is an array of airguns, the amount of energy propagating in various directions depends on the orientation of the array (e.g. Malme et al. 1983). More energy propagates perpendicular to the long axis of the array than parallel to that axis. Independent of that effect, the received level at any particular location is less just below the surface of the water than at deeper depths. This is largely attributable to the release of sound pressure to the atmosphere at the water surface. Greene (1984) found that the received level of seismic noise 3 m below the surface was 4-10 dB less than that 9 m below the surface.

The spectral characteristics of the received sound pulses, as well as their levels, also depend on propagation conditions. In shallow, nearshore waters of the Beaufort Sea, the lowest frequencies (<100 Hz) tend to attenuate more rapidly than do higher frequencies. Thus, when received at a range of many kilometres from the seismic ship, energy in the sound pulses is mainly at 100–500 Hz even though, near the source, there was a major component below 100 Hz (Greene 1982, 1983).

The perceived duration of the pulse tends to increase with increasing range. The noise pulse may be only 0.2 s in duration when received close to the seismic vessel, but is typically 0.5 s long when received 25 km away. This increase is attributable to the multiple paths that the sound energy may take en route from the seismic vessel to the receiver.

Other Studies of Reactions of Whales to Seismic Exploration

The following review of available data on reactions of bowheads and gray whales to seismic impulses is taken, with minor amendments, from Richardson et al. (1985 c). A more general review, including a summary of early inconclusive observations, appears in Richardson et al. (1983).

Bowheads in Summer. -- Bowheads summering in the Canadian Beaufort Sea have been observed in the presence of noise from distant seismic vessels on 21 days during 1980-84. These whales were at ranges 6-99 km from the seismic vessels, and received noise levels were 107-158 dB (Richardson et al. 1985b,c). There was no evidence that these whales were attempting to move away, and the usual types of calls were heard at the usual rates. There were hints of subtle alterations in surfacing, respiration and diving behavior on some occasions. Surface times, number of blows per surfacing, and dive times tended to be low in the presence of seismic noise, and blow intervals tended to be long. However, multivariate and other analyses indicated that it was not possible to determine conclusively whether these weak and inconsistent trends were attributable to the seismic noise.

Four groups of bowheads were exposed to noise pulses from a single 0.66 L (40 in^3) airgun fired 2-5 km away (Richardson et al. 1985b,c). Behavior was observed before, during and after the 20-30 min period of airgun firing. These experiments simulated the onset of seismic exploration by a full-scale seismic vessel several times as far away. A fifth group of bowheads were exposed to a few noise pulses when the airgun was only 0.2-1.2 km away.

During three tests, the general activities of the whales did not change when the airgun started firing. However, during one test at 2-4.5 km range, plus the brief test at 0.2-1.2 km, most bowheads began moving away when the airgun began firing. This indicated that bowheads were able to localize the direction from which airgun pulses were arriving, and to move in the opposite direction. Surfacing and respiration variables did not change dramatically in the presence of airgun noise, but trends were consistent with those in the opportunistic data -- slightly reduced surface times and number of blows per surfacing; slightly increased blow intervals. Call rates and types did not change in any detectable way during airgun experiments.

One test with a full-scale seismic boat showed that bowheads began to orient away from the vessel when it began firing its airguns 7.5 km away. However, the reaction was not strong, and some bowheads continued apparent near-bottom feeding until the vessel was only 3 km away. Whales were displaced by about 2 km. Reactions were not much stronger than those to any conventional vessel.

Bowheads in Autumn. -- Bowheads have been seen in Alaskan waters as close as 3 km from operating seismic vessels (Ljungblad et al. 1980, 1982a, 1984b; Reeves et al. 1983, 1984). Bowhead calls have been heard in the presence of seismic noise in Alaskan waters. During opportunistic observations, there have been no clear indications of whales moving away from approaching seismic boats. Reeves et al. (1983, 1984) described bowheads 'huddling' in a compact group in the presence of seismic noise, but they also observed similar behavior in the absence of such noise. Opportunistic observations of bowheads in the presence of noise from distance seismic vessels provided hints of altered surfacing and respiration behavior, but the results were not consistent or conclusive.

Detailed results from four experiments with full-scale seismic boats in 1984 are not available yet, but there were avoidance reactions when ships were within a few kilometres of bowheads (Ljungblad et al. 1985b, in prep.). There was also a consistent tendency for reduced surface and dive times and for fewer blows per surfacing when seismic vessels were nearby. These tendencies were consistent with the weak trends evident from some opportunistic observations and airgun experiments in the Canadian Beaufort

Sea in summer (cf. Richardson et al. 1985b,c). This consistency suggests that some bowheads do react subtly to noise from seismic vessels many kilometres away.

Migrating Gray Whales. -- Recent tests on gray whales show that this species reacts to strong seismic impulses (Malme et al. 1983, 1984). In 1983, Malme et al. tested reactions to a full-scale seismic vessel at 1-90 km range, and to a 1.64 L (100 in3) airgun at ranges from <1 km to c. 5 km. Average pulse pressure levels of $\geq$ 160 dB//1 µPa produced behavioral reactions: the whales generally slowed, turned away from the noise source, and increased their respiration rates. They sometimes moved closer to shore, or into a 'sound shadow' created by topography. The $\geq$ 160 dB average pulse pressure level corresponded to peak levels $\geq$ 170 dB, and to ranges <5 km from the full-scale vessel and <1 km from the single airgun. There was also some evidence of behavioral reactions to seismic noise with average pulse pressure levels of 140-160 dB (Malme et al. 1983).

The 1984 study (Malme et al. 1984) showed that some gray whales began to deflect their tracks as much as 2 or 3 km away from the 1.64 L airgun. However, by another measure the radii of 10%, 50% and 90% avoidance were 750 m, 400 m and 100 m (effective received levels 164 dB, 170 dB and 180 dB, respectively). In the situation studied by Malme et al., these levels were equivalent to those 2.8, 2.1 and 1.2 km from a full-scale seismic vessel.

In general, uncontrolled observations in Canadian and Alaskan waters have shown that bowhead whales often tolerate strong seismic pulses without displaying any avoidance reaction or other pronounced response. However, subtle behavioral effects have sometimes been suspected in the presence of seismic vessels and during tests with one airgun. The recent experiments on bowheads and gray whales have demonstrated that avoidance reactions do occur when seismic noise is intense (more than about 160 dB//1 µPa), i.e. when a full-scale seismic ship is within a few kilometres. It is possible that subtle effects occur at considerably greater ranges.

Regulatory Actions in the Alaskan Beaufort Sea

Us. federal agencies planning activities that might affect an endangered species are required, under the Endangered Species Act, to consult with the federal agency responsible for managing that species. The National Marine Fisheries Service (NMFS) is responsible for managing bowhead whales. In 1978 the Department of the Interior was planning the first sale of offshore oil leases in the Alaskan Beaufort Sea, and consequently it began consultations with NMFS regarding the potential effects of such a sale on bowhead whales.

The initial determinations by NMFS, in 1978 and 1979, were that insufficient information existed to conclude whether the lease sale would jeopardize the continued existence of bowheads, or would harm habitat critical to them. This conclusion was a major factor in the initiation of the NOSC study of bowhead distribution and movements in Alaskan waters, and the LGL study of behavioral reactions to offshore industrial activities.

In a further opinion in 1980, NMFS indicated that knowledge is inadequate to assess the effects on bowheads of noise from seismic exploration. In 1981, NMFS recommended that seismic exploration be prohibited in the lease area east of Prudhoe Bay from 1 September to 31 October, and in the lease area west of Prudhoe Bay from 15 September to 31 October. The difference in recommended 'closure' dates east and west of Prudhoe Bay reflected the fact that bowheads begin to migrate west through the Alaskan Beaufort Sea in September; areas east of Prudhoe Bay are used by bowheads earlier in the autumn than are areas farther west. NMFS suggested that these recommended closure dates could be modified if aerial surveys revealed that bowheads were moving westward earlier or later than normal.

Reeves et al. (1983) provide a more detailed account of the regulatory actions summarized above, and also describe the NMFS opinions issued to cover the 1982 season.

Objectives

As a result of the above considerations, the Bureau of Land Management requested that a study be done in Alaskan waters in the autumn of 1981 with the following overall objectives:

1. Document bowhead behavior when seismic vessels are operating near whales,
2. Document bowhead behavior when the whales are not in the potential zone of influence of seismic vessels,
3. Document the environmental (e.g. ice, weather) and acoustic circumstances of the behavioral observations,
4. Compare behavior when the whales are within vs. not within the potential zone of influence of the seismic vessels, and
5. Compare the results of this autumn study in Alaskan waters with those obtained during the LGL summer study of bowheads in Canadian waters.

Another requirement specified by the Bureau of Land Management was as follows: "In the event that the contractor observes significant change in bowhead" whale behavior which, in his judgement, is related to geophysical vessel operation, operators of geophysical vessels will be so notified. In such a circumstance, the contractor will tell the vessel operator the likely period of time that bowhead whales would be present within the zone of influence of the probable disturbing factor. It will not be the contractor's responsibility to advise the geophysical vessel operator as to possible remedial action related to vessel operation."

Approach

The behavioral studies in the Alaskan Beaufort Sea during the autumn of 1981 (12 September through 5 October) were a joint effort of LGL and NOSC. The project used the aircraft and other facilities that were in place for the NOSC study of the distribution and movements of bowheads (Ljungblad et al. 1982a). From 12 to 20 September, the behavioral observations were obtained by NOSC personnel. From 21 September to 5 October, M.A. Fraker of LGL flew with the NOSC crew. Behavioral data were obtained as the observation aircraft circled over the whales. This is the same general approach as was used during the LGL study of bowhead behavior in the Canadian Beaufort Sea in the summers of' 1980-84. Similar methods were used in subsequent studies in the Alaskan Beaufort Sea in the autumns of 1982-84 (Reeves et al. 1983, 1984; Ljungblad et al. 1984b, in prep.).

The same aircraft was used for both the standard aerial survey program conducted by NOSC and for the behavioral study conducted by NOSC and LGL. This, along with the usual deterioration in weather and light conditions in autumn, limited the quantity and quality of information that could be collected. (During follow-up studies in 1982-84, the survey and behavioral programs were done with separate aircraft.) This report describes the results of the 1981 behavioral study; Ljungblad et al. (1982a) describes the results of the simultaneous aerial survey program. The latter report includes information about the routes flown and the numbers and locations of whales during each of the behavioral observation flights described here.

METHODS

Study Area

The study was based at Deadhorse, Alaska, in the Prudhoe Bay area. We searched for whales in the area from Herschel Island off the Yukon coast (longitude 139°W) west to Smith Bay (154°W; Fig. 1). Two types of flights were performed: transect survey flights designed to document the distribution, numbers and movements of whales (the main NOSC study), and flights whose specific purpose was to study bowhead behavior. During the latter type of flight, we searched for whales in places where bowheads were expected. In particular, searches were concentrated near the" 20-m water depth contour, with special emphasis on the eastern part of the Alaskan Beaufort Sea (Demarcation Bay area). Flight routes and sighting locations for both the standard surveys and the search/behavior flights are mapped in Ljungblad et al. (1982a). Most behavioral observations were obtained between Kaktovik and the Alaska-Yukon border (Fig. 1).

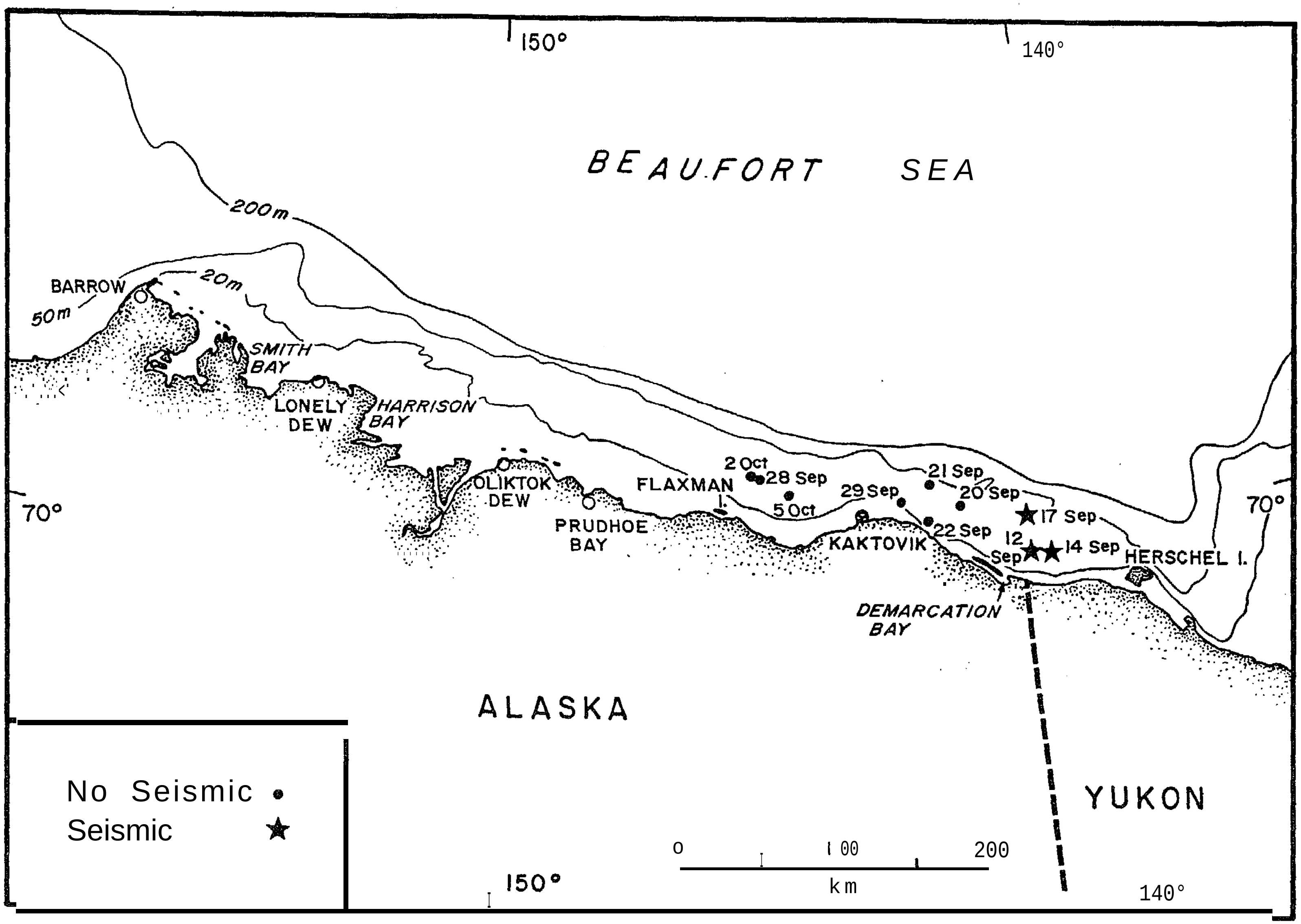

Fig. 1. The Alaskan Beaufort Sea study area, showing locations where behavioral observations were obtained in autumn 1981.

Search and Observation Procedures

The aircraft used for both the standard NOSC transect surveys and for the NOSC/LGL behavioral work was a specially modified Grumman 'Super Goose' (N780). This amphibious aircraft differed from a standard Goose in that it had been lengthened by about 1 m, and the two piston engines had been replaced by turboprop engines. A very low frequency navigation system (Global Navigation System GNS-500) provided information about aircraft position and heading. Large windows in the cockpit provided good visibility for the four personnel seated there, although the wingtip sometimes obscured bowheads that were being circled.

The stall speed of the 'Super Goose' was quite high (about 220 km/h in a turn). Consequently, it was necessary to maintain an airspeed of about 260 km/h while circling above whales. This limited the maneuverability of the aircraft. The average radius from the whales to the circling aircraft was necessarily greater than during LGL's study of bowhead behavior in summer, when the observation aircraft has been a Britten-Norman Islander circling at about 148 km/h.

During searches for bowheads, survey altitudes ranged between 153 m (500 ft) and 305 m (1000 ft). Similarly, transect surveys were flown at 153 m altitude. When bowheads were found and behavioral observations were beginning, the aircraft climbed to an altitude of at least 457 m (1500 ft) when the cloud ceiling permitted. Some observations were obtained from altitudes as high as 610 m (2000 ft). Unfortunately, on 6 of the 10 days with detailed behavioral observations, low ceilings forced us to circle at altitudes below 457 m (Table 1). Bowhead behavior is sometimes (but not always) disturbed if an Islander aircraft circles overhead at an altitude below 457 m (Richardson et al. 1985b,c). Also, the aircraft's wingtip interrupts the observers' view of the whales more frequently when the aircraft is low than when it is high.

During transect surveys and searches for bowheads, there were two observers (plus the pilot) on the left side of the aircraft and one observer (plus the co-pilot) on the right. During behavioral observations, the

Table 1. Circumstances of behavioral observations, Alaskan Beaufort Sea, 12 Sept-5 Oct., 1981.

Date Flight Number	12 Sept 97	14 Sept 100	17 Sept 102	20 Sept 104	21 Sept 105	22 Sept 107	28 Sept 112	29 Sept 114	2 Oct 116	5 Ott 118
Latitude (Average)	69°50′	69°49′	70°02′	70°07′	70°16′	70°03′	70°22′	70°11′	70°23′	70°18′
longitude (Average)	140°58′	140°30′	140°50′	141°55′	142°29′	142°29′	145°28′	143°10′	145°32′	144°56′
Water Depth (m)	27	30	40	27	44	24	35	20	37	33
Sea State	1-2	1-2	2-3	1-2	4-5	1-3	3-5	3-4	3-5	3
Ice Cover (Tenths)	0-1	1	1	0-1	0-1	0-1	0	1	1-3	35 (New)
Aircraft Altitude (m)	305-610*	152-563*	274-57P	183-305	150-271	213-579*	148-183	244-427	137-244	152-244
Geophysical Sounds?	Yea	Intense	Yes	No	2 Pulses	No	No	No	No	No
Whale Sounds?	Yea	Yes	Yes	Yes	None	Yea	Yea	Yea	Yes	Yes
Number of Bowheads	11	15**	11	9+ ***	3	7	6+ ***	5+ ***	12	5+ ***
Activity of Bowheads	Feeding? Slow Travel Calling	Feeding? Little Movt Calf Play Calling	Feeding? Active Soc- ializing Calling	Some Soc- ializing; Resting Calling	Swimming	Feeding? Defecation Little Movt (killing	Feeding? Calling	Feeding? Defecation Socializing Calling	Feeding? Little Movt Calling	Feeding? Little Movt calling

* Altitude 457 m or more for most observations.
** Including one cow-calf pair.
*** Number of bowheads includes only those where behavioral observations were conducted.

co-pilot moved to the cockpit seat behind the pilot, and the aircraft circled to the right. The primary observers were in the co-pilot's seat and a cockpit seat directly behind it. These observers dictated their observations into tape recorders. One of the other observers occupied a left rear seat while we circled whales; this observer was also responsible for data recording, launching sonobuoys, and recording their signals.

Beginning on 21 September, fluorescein dye markers (Würsig et al. 1982) were dropped near whales to assist the pilot in remaining at the correct location while the whales were below the surface and unobservable. The presence of ice pans or other cues was also helpful in maintaining station above the whales, especially on 14 September.

From 21 September onward, one primary observer used binoculars (Leitz Trinovid 8x40B) to observe details of behavior. Because of the great distance from the circling aircraft to the whales, binoculars are necessary in order to be certain of discerning details of behavior, especially the less conspicuous respirations, and to identify individual whales positively.

Behavioral Data Recorded

Behavioral information that was recorded included the group size and general activity of the whales (feeding, socializing, traveling, etc.), respiration parameters (blow intervals and number of blows per surfacing), length of time at surface, duration of dive, orientations, turns, and inter-animal distances. Any of these variables may change when bowheads are disturbed by industrial activities (Richardson et al. 1985b,c).

When possible, the observers concentrated on individual bowheads that had distinctive markings. Only when whales are individually recognizable, or when it is clear that only one animal is present, is it possible to obtain reliable data on durations of dives.

Definitions of behavioral terms generally followed those of the summer study in Canadian waters (e.g. Würsig et al. 1982, 1985a). However, in view of the difficult conditions and limited opportunities for observations in this study, our criteria for acceptance of data as reliable were somewhat more liberal than the criteria applied in the summer study. For example, the operational definition of 'surface time' during this study was from first appearance (or first blow) to submergence (or last blow if submergence was not specifically noted). In the summer study, surface times are accepted only if the exact times of appearance and submergence were noted. Consequently, surface times would probably average a few seconds shorter by the criteria used in this study as compared with the likely average if the summer procedures had been used. Because dive durations are complementary to surface times, average dive durations recorded in this study are probably a few seconds longer than would have been recorded by the procedures used in the summer study.

Orientations were recorded in the same way as during the summer study. The heading of the whale or group of whales when it surfaced was recorded as the orientation for that surface interval. In addition to the observations made while we circled over whales for extended periods, observations of general activities and orientations were often obtained during transect surveys conducted by NOSC (Ljungblad et al. 1982a).

Some data on intervals between successive blows and number of blows per surfacing were collected. However, we have not presented these data here because their reliability was questionable. Blows were sometimes difficult to detect because of the wide circles necessitated by the high speed of the Super Goose. Also, because of the low altitudes at which we often had to fly to remain below clouds, the angle of observation was such that the observers! view of the whales was frequently blocked by the wingtip. In the case of dive times and surface times, these problems were not as severe; dive times and surface times are presented in this report.

Sonobuoy Recordings of Underwater Sounds

On each of the 10 occasions when detailed behavioral observations were obtained, we dropped one or two sonobuoys near the whales in order to record any underwater sounds produced by the whales, by seismic vessels, and from other sources. Three types of sonobuoys were used -- models AN/SSQ-41A, AN/SSQ-41B, and AN/SSQ-57A, with frequency responses of 10 Hz to 6 kHz, 10 Hz to 20 kHz, and 10 Hz to 20 kHz, respectively. Sounds received by the sonobuoy hydrophore (18 m deep) were amplified, telemetered via the sonobuoy's VHF transmitter to a broadband receiver (Defense Electronics GPR-20) on the aircraft, and recorded on a dual track Nagra IV SJ tape recorder. Signals were monitored via headphones while recording on one track, and behavioral observations were dictated onto the second track.

In this report, we use the sonobuoy data simply to indicate whether whale sounds and/ or seismic impulses were detectable near the whales that were being observed. We assume that whales were not exposed to seismic sounds if we could not detect such sounds on sonobuoy recordings obtained during the behavioral observation session. When we could detect seismic impulses, we assume that the whales were exposed to seismic noise. It is possible that whales might not detect weak impulses that we could hear. This is especially likely if whales remained at the surface, where received noise levels were probably several decibels less than those at the depth of the sonobuoy hydrophore (Greene 1984).

RESULTS

Ice Conditions

Ice conditions in the study area during September 1981 ranged from open water to 5/10 coverage between the north coast of Alaska and 72"N latitude. North of 72°N, ice coverage varied from open to 7'/10. The lease areas were covered by a maximum of 2/10 ice on the northern edges, but open water was predominant. Some residual pieces of old ice were grounded and stacked up on the barrier islands.

Relatively ice-free conditions persisted south of 72°N until 30 September. Freeze-up began during a storm on 1 October. By 3 October, the new ice was thick enough to support polar bears, as evident from our sightings of numerous bear tracks thereafter. Ice cover was 9/10 grease ice south of the barrier islands. Open water prevailed from the north sides of those islands out to the 20 m depth contour. North of this strip of open water, ice cover was 5/10 to 9/10. The Sale 71 and State-Federal lease areas averaged 9/10 ice cover by 4 October. Ice cover averaged 7/10 east of Flaxman Island on 4 October; coverage increased to 8/10 in this area by 7 October. From 9 October until the end of the NOSC study on 15 October, ice cover from Point Barrow to Demarcation Bay averaged 8/10 to 9/10 except along the 20 m contour, where the cover was predominantly 5/10 - 8/10.

Ice cover at each of the ten locations where detailed behavioral observations were obtained is summarized in Table 1. There was little or no ice near the whales observed on 12 through 29 September. Ice cover was about 1/10 - 3/10 during observations on 2 October, and 3/10 - 5/10 new ice on 5 October.

Seismic Exploration

We are aware of six seismic vessels operating in the Alaskan Beaufort Sea for some part of our study period (12 September - 5 October 1981). One vessel, the 'Arctic Fox', ceased operations on 12 September, and the other five vessels ceased operations between 16 and 28 September. There was no seismic exploration in the Alaskan Beaufort Sea after 28 September. Table 2 summarizes our limited information about the daily locations of the six vessels. This information was obtained from two sources: (1) reports to us from the geophysical exploration companies, and (2) our sightings of seismic vessels at sea. We rarely obtained more than one position report for each ship each day, so Table 2 provides only a general indication of the area within which each ship was operating.

Another seismic vessel, the 'Edward O. Vetter', was operating in Canadian waters just east of the Alaska-Yukon border on 14 September. On that date, we observed whales in Canadian waters about 15 km from this vessel.

Most seismic exploration in the Alaskan Beaufort Sea during this study was in the Sale 71 area in and near Harrison Bay. This was far to the west of the locations where we studied bowhead behavior. Only the 'Edward O. Vetter' and the 'GSI Mariner' operated in the general area where we studied bowheads.

Table 2. Daily locations of five seismic vessels operating in the Alaskan Beaufort Sea, autumn 1981. On most days we know the location of each vessel at only one time. A sixth vessel, 'Arctic Fox', ceased operationa on 12 September.

Vessel	Position/ Shooting	Date (day/Sept 1981) 12	13	14	15	16	17	18	19	20
'Western Anchorage'	Position	N of Harrison Bay	Harrison Bay	71″00′ 149°30′	71°20″ 152″00′	Heading S Chukchi Sea	-			
	Active?	Yes	Yes	?	?	No				
'Western Inlet'	Position	Harrison Bay	W end of Harrison Bay	70°15′ 150″45′	E end of Harrison Bay	71°15′ 152°00′	71°07′ 153°20′	70°38′ 148°30′	70°45′ 150°20′	70″50″ 150°20′
	Active?	Yes	Yes	?	Yes	?	?	?	Yes	Yes
'Arctic Star'	Position	N of Smith Bay	N of Smith Bay	70″48′ 155″55′	71°16′ 155°30′	71°51′ 155″35′	71°15′ 151°00′	71″00′ 151°30′	70°49′ 152°08′	71°00′ 151°09′
	Active?	Yes	?	?	Yes	?	?	No	No	Yes
'GSI Mariner'	Position	70°39′ 146°46′	70°39′ 146″46′	70°28′ 145°14′	70°26′ 142°25′	69″56′ 140°38′	70°23′ 142°50′	70°47′ 142°52′	Herschel 1s1.	Herschel 1s1.
	Active?	Yes	Yes	?	Yes	?	?	?	No	No
'Krystal Sea'	Position	N of Oliktok	70°37′ 150°23′	70°49′ 151°18′	70°42′ 150°39′	70″45′ 150°40′	70°49′ 150″13′	70°48′ 151″18′	70°33′ 148°52′	70″49′ 150″26′
	Active?	Yes	?	?	Yes	?	?	?	Yes	?
		21	22	23	24	25	26	27	28	29
'Western Anchorage'	Position									
	Active?									
'Western Inlet'	Position	W of Barrow	Heading for Dutch Hbr.							
	Active?	No	No							
'Arctic Star'	Position	70°41′ 151°30′	70°12′ 151°16′	71°15′ 150″05′	NO CONTACT		Harrison Bay	70°53′ 151°22′	70″52′ 151°26′	
	Active?	?	Yes	Yea			No	Yes	No	
'GSI Mariner'	Position	70°05′ 141″58′	70°56′ 146°23′	70°54′ 147°47′	NO CONTACT		Cross 1s1.	Heading to Tuktoyaktuk		-
	Active?	Yes	Yes	?			No	No		
'Krystal Sea'	Position	70″50′ 150°22′	70″49′ 151″24′	71°20′ 151°04′	NO CONTACT		W of Reindeer 1s1.	70°46′ 150″07′	71°00′ 151″18′	West Dock
	Active?	?	?	?			No	Yes	No	No

'Vetter' is a 56-m ship that, in 1981, used an array of airguns with total volume 2000 in3 (33 L). 'Mariner' is a 36-m ship that, in 1981, used an array of 27 airguns with total volume 23 L and source level 246 dB//1 µPa-m (G. Bartlett, GSI, pers. comm.).

Bowhead Behavior in the Absence of Seismic Noise

General Characteristics of the 1981 Autumn Migration

In the autumn of 1981, transect surveys of the Alaskan Beaufort Sea were flown from 15 August to 15 October, mostly south of the 100 m isobath and within 80 km of the coast. Almost all bowhead sightings were between the 20 and 50 m isobaths. The migration across the Alaskan Beaufort Sea lasted from 7 September to at least 15 October with large numbers of sightings from 12 September to 7 October. The majority of the Western Arctic bowhead population remained in Canadian waters until mid September in 1981 (Davis et al. 1982). The migration was protracted; there were still bowheads north of Kaktovik on 9 October. The prolonged migration in 1981 may have been related to the relatively light ice coverage.

Throughout September and October, more whales were oriented westward than in any other quadrant, but some individuals were oriented in other directions (Ljungblad et al. 1984a, p. 99). Over 66% of all sightings were in open to 1/10 ice cover, and only 2% were in >9/10 ice cover. General activities were classified as traveling (56%), resting (16%), feeding (14%), and calf nurturance (l%); for 13%, no activity was recorded. Whales that were thought to be feeding were observed throughout September and October, but most often in late September near Demarcation Bay. In that area, whales believed to be feeding tended to dive and surface more or less synchronously in the same general area; their movements were slow and not in any one consistent direction. In summary, the migration through the light ice in the Alaskan Beaufort Sea in the autumn of 1981 was slow and prolonged, and many of the groups of whales were feeding or resting when seen (Ljungblad et al. 1982a, 1984a).

The following subsections present our results from the seven days when we circled bowheads to observe their behavior in the absence of noise from seismic vessels.

<u>20 September 1981</u>

On this date, we flew from Deadhorse northwest beyond Oliktok and then east along or south of the 20 m depth contour to about Demarcation Bay. The return flight back to Deadhorse was also along or inside the 20 m contour. There was some patchy fog and general low overcast, which prevented us from flying above 305 m. At least 38 bowheads were sighted, most near 70°07'N, 141°55'W (Ljungblad et al. 1982a, p. A-171). The whales did not respond to the Super Goose aircraft in any obvious way. However, experiments in summer have shown that an Islander aircraft circling at altitude 305 m usually causes subtle changes in behavior, such as reduced blow intervals (Richardson et al. 1985b,c). Subtle effects of this type would not be detectable during ‘uncontrolled! observations of the type obtained in the present study.

Most of the detailed behavioral observations came from nine bowheads. Of these, four were in a group of socializing animals. A sonobuoy dropped at their location revealed whale sounds when the whales were on the surface and just before they surfaced. No seismic noise was detected. The group of four whales may have been responsible for most or all of the whale sounds, since calls were heard when the group was at or approaching the surface but not during dives by that group. The most prominent type of sound was an elephant-like screech, which occurred just before the group of four whales surfaced. Before most dives, the whales raised their flukes fully out of the water. On one occasion, a tail slap preceded the dive. One specific member of the group appeared to lead, and headings varied.

The whales in the socializing group dove and surfaced more or less synchronously. Surfacings of this group averaged 2.5 ± s.d. 0.5 min in duration (range 1.9-3.3 rein, n=6). Dives by this group averaged 16.2 ± 2.2 min in duration (range 14.3-18.7 min, n=4, one questionable 19.0 min case excluded). Because all whales in the group did not surface and dive at exactly the same second, the above values are approximate and are not directly comparable to values from precisely-timed surfacings and dives by individual whales.

Other individual whales not in the above group surfaced for averages of 2.4I ± s.d. 0.84 min (range 1.0-3.5 rein, n=10; Table 3A). Their dives averaged 15.3 ± 10.4 min (range 7.8-33.3 rein, n=5; Table 3B). The 33.3 min dive was 2 min longer than the longest dive recorded during the summers of 1980-84 in the Canadian Beaufort Sea (cf. Würsig et al. 1984, 1985b). We have no specific reason to question the accuracy of this observation. However, 33.3 min is about twice as long as most dives observed on this date. It is possible that we missed a surfacing during the 33.3 min period. If the 33.3 min case is excluded, the mean for individual whales becomes 10.8 ± 3.1 min (range 7.8-15.0 rein, n=4). Note that the observation aircraft was low enough on this date (altitude 183-305 m) that all surface and dive times may have been affected subtly by the presence of the aircraft.

<u>21 September 1981</u>

On 21 September we” flew from Deadhorse eastward to a point north of Demarcation Bay and return. Most of the route was near the 20 m contour (Ljungblad et al. 1982a, p. A-173). A search of the area near 70°16'N, 142°29'W, where the seismic vessel 'GSI Mariner' was expected to operate later in the day, revealed three bowheads. The sea was rough (sea state 4-5), and low overcast forced us to fly below 275 m altitude (900 ft). Each of the three whales was seen only briefly, and few data were obtained because of the poor weather conditions. A sonobuoy was dropped but no whale sounds were detected. The sonobuoy detected two isolated noise pulses, probably from a seismic vessel testing or depressurizing its airgun system, but there was no sequence of pulses. We returned to Deadhorse after losing track of the whales.

<u>22 September 1981</u>

On this date we flew from Deadhorse eastward near the 20 m contour to about 142°20'W and return (Ljungblad et al. 1982a, p. A-177). The weather was foggy to partly cloudy, with generally good visibility and low to moderate

Table 3. Durations of surfacing and dives by individual bowheads in the presence and absence of seismic noise, 12 September-5 October 1981. No data concerning calves were obtained. 'Average' surface and dive times for groups of whales acting more or less synchronously are excluded, as are all questionable values.

		Mean	s.d.	n	Minimum	Maximum
A. SURFACE TIMES (rein)						
No Seismic Noise						
20 September	x	2.41	0.84	10	1.00	3.50
22 September		2.31	0.76	7	1.32	3.65
28 September	x	1.93	1.07	5	1.08	3*75
29 September	x	0.79	0.43	9	0.25	1.50
2 October	x	1.42		1		
5 October	x	1.81	0.76	10	0.25	2.67
Al 1		1.82	0.94	42	0.25	3.75
Seismic Noise						
12 September		1.85	1.02	12	0.55	3.58
14 September+		2.26	1.16	10	0.83	4.75
17 September		3.29	2.52	6	0.75	7.00
Al 1		2.30	1.54	28	0.55	7.00
B. DIVE DURATIONS (rein)						
No Seismic Noise						
20 September	x	15.31	10.43	5	7.75	33.33*
22 September		10.86	1.77	7	8.67	14.00
28 September**	x			0		
29 September	x	18.16	10.85	3	5.82	26.17
2 October**	x			0		
5 October	x	11.81	3.44	5	5.97	14.83
Al 1		13.31	6.81	20	5.82	33.33
Seismic Noise						
12 September		8.32	3*11	5	5.00	12.33
14 September+		13.58	2.02	4	11.67	16.08
17 September				0		
Al 1		10.65	3.75	9	5.00	16.08

x Observation aircraft circled at altitude <457 m on this date (cf. Table 1).

\+ Most surface times and all dive times recorded on 14 September involved a female bowhead that was accompanying a calf.

* The dive duration on 20 September averages 10.81 ± 3.14, n = 4, max = 15.0, if the unusual 33.33 value is excluded (see text).

** Data for 28 September and 2 October excluded because of uncertainties caused by the high sea state.

sea state (l-3). Seven bowheads were found at several sites east of Kaktovik, and detailed behavioral observations were obtained at 70°03'N, 142°29'W over about 2 h. We circled at about 550 m (1800 ft) altitude, just below the clouds. A sonobuoy dropped near the whales revealed whale sounds but no seismic noise.

The whales were apparently feeding in the water column; their behavior was very similar to that of whales feeding in the' Canadian Beaufort Sea in summer (cf. Würsig et al. 1982, 1985a,b). The whales within any one group tended to surface and dive synchronously. They did not appear to make any net movement, and headings were not in any consistent direction. On one occasion, we saw a cloud of reddish feces in the water. Würsig et al. (1982) believe that defecation is an indication of recent feeding.

One of the whales was distinctively marked with a white triangular patch on the tail, and this mark allowed us to follow this individual through seven full surface/dive cycles. The seven surfacings averaged 2.31 ± s.d. 0.76 min in duration (range 1.3 - 3.7 rein, Table 3). The seven dives averaged 10.86 ± 1.77 min (range 8.7 - 14.0 rein). Four of the surfacings ended with a pre-dive flex, in which the head and peduncle are raised relative to the middle of the body . Pre-dive flexes are often seen during summer in the Canadian Beaufort Sea (Würsig et al. 1985a,b). The observation aircraft was high enough during these observations that aircraft disturbance was unlikely (cf. Richardson et al. 1985b,c).

28 September 1981

On 28 September we flew northwest to the location of a seismic vessel north of Harrison Bay, and then east near the 20 m contour to 145°28'W, northeast of Flaxman Island (Ljungblad et al. 1982a, p. A-187). About 14 bowheads were found at the latter location. We observed five or six of these whales in detail. Observation conditions were poor: the sea was rough (sea state 3-5), and low clouds forced us to circle at an altitude of about 183 m (600 ft). On two occasions we suspected that the observation aircraft disturbed the whales sufficiently that they dove in response. A sonobuoy dropped near the whales revealed whale sounds. No seismic sounds were detected.

As during the previous flight on 22 September, the whales appeared to be feeding in the water column. There was a high degree of synchrony in their surfacings and dives. Five surfacings averaged 1.93 $\pm$ s.d. 1.07 min in duration (Table 3). These values may have been affected subtly by the low altitude of the observation aircraft. Several dives were timed, but those results were questionable because of the high sea state as well as the low aircraft altitude.

29 September 1981

On this date we searched for bowheads near the 20 m contour from Deadhorse east to about 143°10'W. Systematic transect surveys were conducted in the State-Federal lease area during the return flight. Bowheads were found in two areas during this flight: near 145°40'W and near 143°10'W. The detailed behavioral observations were obtained from five or six whales in the latter group, which was about 20 km east of Kaktovik. Because of low cloud, the aircraft circled at an altitude of about 400 m (1300 ft) for most of the observations. No obvious reactions to the aircraft were noted at the location east of Kaktovik but, as mentioned in the 20 September section above, there could have been subtle effects that would not have been detectable by us. The sea state was moderate to high (3-4).

A sonobuoy was dropped at the location of the detailed observations, and bowhead sounds were recorded. No seismic sounds were detected; by this date, all seismic vessels had ceased operations for the year.

The whales were in a relatively cohesive group and they tended to dive and surface synchronously. On one occasion, a whale defecated reddish feces just before it dove. As on 22 and 28 September, we suspect that the whales were feeding below the surface. In addition, however, there also were some social interactions. At one time there was at the surface a pair of animals separated by two body lengths, a third whale four lengths from the pair, and a fourth whale about 10 lengths from the others. Instances of active socializing included one apparent chase, close association of two individuals, and the pushing of one whale's peduncle by another whale. Also, twice during the observation period we observed underwater blows. Underwater blows sometimes seem to be associated with socializing (Würsig et al. 1985b). One of the adults at the location east of Barter Island was accompanied by a large calf, which was on the right side of the adult.

Nine surfacings averaged 0.79 $\pm$ s.d. 0.43 min in duration, and three dives ranged from 5.8 to 26.2 min long (Table 3). These values may have been affected by the low altitude of the aircraft.

When whales were seen at the second location, near 70°20'N, 145°40'W northeast of Flaxman Island, the aircraft was at altitude 305 m (1000 ft). Three whales dove in apparent response to the aircraft. Two whales at this location were oriented west and were apparently actively migrating.

2 October 1981'

On 2 October, we searched from Deadhorse east to Kaktovik and return (Ljungblad et al. 1982a, p. A-197). The only bowheads sighted were northeast of Flaxman Island at 70°23N, 145°32'W, near one of the locations where bowheads were sighted on 29 September. Behavioral observations were obtained from at least eight bowheads (groups of 5 and 3 whales). Ice cover was 1/10 - 3/10, mostly single-year pan ice. Because of low cloud, the aircraft again had to circle at low altitude (137-244 m, 500-800 ft). Observations were also hampered by rough seas (sea state 3-5). Two sonobuoys detected bowhead sounds but no seismic noise.

The whales were apparently feeding in the water column. They were surfacing and diving with no consistent movement in any one direction. One group of whales was surfacing and diving more or less synchronously. Their surfacings lasted an average of 2.5 $\pm$ s.d. 0.7 min (range 1.3-2.9 rein, n=5). Two accurately timed dives were 11.8 and 13.3 min in duration, and two additional dives were roughly 12.7 and 14.2 min in duration. Again, these values may have been affected by the low altitude of the aircraft.

5 October 1981

On 5 October, the last date with behavioral observations, we flew eastward from Deadhorse and found several bowheads between Flaxman Island and Kaktovik (Ljungblad et al. 1982a, p. A-201). Behavioral observations were obtained from five of these whales. Ice cover near the whales was 3/10 - 5/10 newly formed ice. Observation conditions were poor. The sea was moderately rough (sea state 3) and low cloud forced us to circle at only 152-244 m altitude (500-800 ft). Two sonobuoys were dropped; they detected bowhead sounds but no seismic noise.

The five bowheads that were observed appeared to be feeding in the water column . They did not appear to be moving consistently west (or in any other direction). The surfacings were in areas of open water, not through the new ice.

Ten surfacings by various individual whales averaged 1.81 + s.d. 0.76 min (Table 3). Five dives averaged 11.81 ± 3.44 min. However, all values from 5 October may have been affected by the low altitude of the observation aircraft.

Bowhead Behavior in the Presence of Seismic Noise

On three dates in 1981, we obtained detailed observations of behavior in the presence of noise from seismic exploration.

12 September 1981

On this date we searched near the 20 m contour from Deadhorse east to Demarcation Bay, and then west to Lonely (Ljungblad et al. 1982a, p. A-153). Groups of three and seven bowheads were observed about 20 km offshore near the Alaska–Yukon border; these two groups later merged. The aircraft flew at altitude 305 m (1000 ft) while searching for whales, but climbed to 457 and later 610 m (1500 and 2000 ft) to circle for behavioral observations. Observation conditions were relatively good (sea state 1-2).

A sonobuoy dropped near the whales detected both whale sounds and seismic noise. We do not know which seismic vessel was responsible for the sounds reaching the whales' location on this date. All six seismic vessels known to be operating in the Alaskan Beaufort Sea were 200 km or more to the west (Table 2). We presume that the seismic noise did not come from one of these vessels, but instead came from a vessel in Canadian waters.

The received seismic sounds varied considerably in intensity and characteristics during the 45 min of recording. Initially, the pulses were strong with a descending (in intensity) 'tail' nearly 2 s in duration. The pulses later became weak, but subsequently became strong again. During this last phase, each pulse was followed not by a 'tail', but by an 'echo' 0.4 s after the pulse. By the end of the recording period, the 'echoes' became almost as intense as the main pulses. Possible explanations for the great variation in received signal strength and characteristics include changes in aspect, range, and propagation paths.

There was no indication of any unusual behavior on this occasion in the presence of seismic noise. The whales were diving and surfacing, and appeared to be feeding in the water column. They were moving slowly southeast. Surface times averaged 1.85 ± s.d. 1.02 min (range 0.6-3.6, n=12; Table 3A). Five dives by one individual averaged 8.32 ± 3.11 min (range 5.0-12.3 rein; Table 3B). With the exception of the shortest dive, 5.0 rein, the surface and dive times observed on this date were within the ranges observed in the absence of seismic noise (Table 3). Dives shorter than 5 min in duration have been observed commonly in other studies of bowheads (Ljungblad et al. 1984b; Würsig et al. 1984), so' we do not consider the one short dive observed in the presence of seismic noise to be unusual.

<u>14 September 1981</u>

On this date, we searched near the 20 m contour from Deadhorse eastward beyond Demarcation Bay into Canadian waters. There was fog and poor visibility over most of this area, but east of Demarcation Bay there was unlimited visibility, clear skies, sea state 1-2, and 1/10 ice. Many bowheads, including one cow-calf pair, were found in this area of favorable weather, at 69°49'N, 140°30'W (water depth 30 m). We were at altitude 152-213 m (500-700 ft) when we first found the whales, but we then climbed and observed them from 488 m a.s.l. (1600 ft) or higher.

When we arrived at 16:39, the bowheads were dispersed over a 2 km^2 area and were apparently feeding. A sonobuoy dropped near the whales detected intense noise pulses, so a second sonobuoy was dropped nearby (Fig. 2). When we first began observing the whales, the seismic vessel ‘Edward O. Vetter' was firing its airgun array 19 km to the southwest. 'Vetter' was traveling due east at 4 knots (7.4 km/h) in water about 26 m deep. By the end of our observations, 2.3 h later, 'Vetter' was about 13 km S of the whales (Fig. 2) . During this entire period the whales were near four ice pans, which provided good positional reference points.

When sonobuoy recordings began, each seismic signal was a strong pulse with a 4 s ‘tail’. Later, the pulses became longer. Still later, each signal was received as two pulses at 0.5–s intervals; reverberations continued long enough to merge into the next pair of pulses 12 s later. The two pulses could have represented arrivals by bottom and water paths, or by direct and reflected paths. There was a noticeable increase in intensity over the 2 h of recording.

During the observation period, the seismic vessel moved eastward, partially but not directly toward the whales (Fig. 2). The whales did not appear to alter their general activities. Most whales surfaced and dove repeatedly; they appeared to be feeding in the water column, although this could not be observed directly. During their repeated surfacings and dives, they moved slowly to the southeast and then to the northwest (see sequentially numbered locations on Fig. 2). Their net movement was about 3 km. One adult whale with an all-white tail was accompanied by a calf; these animals were the easiest to reidentify after dives. The behavior of the calf appeared playful. On several occasions it swam in front of its mother, where it breached two or three times.

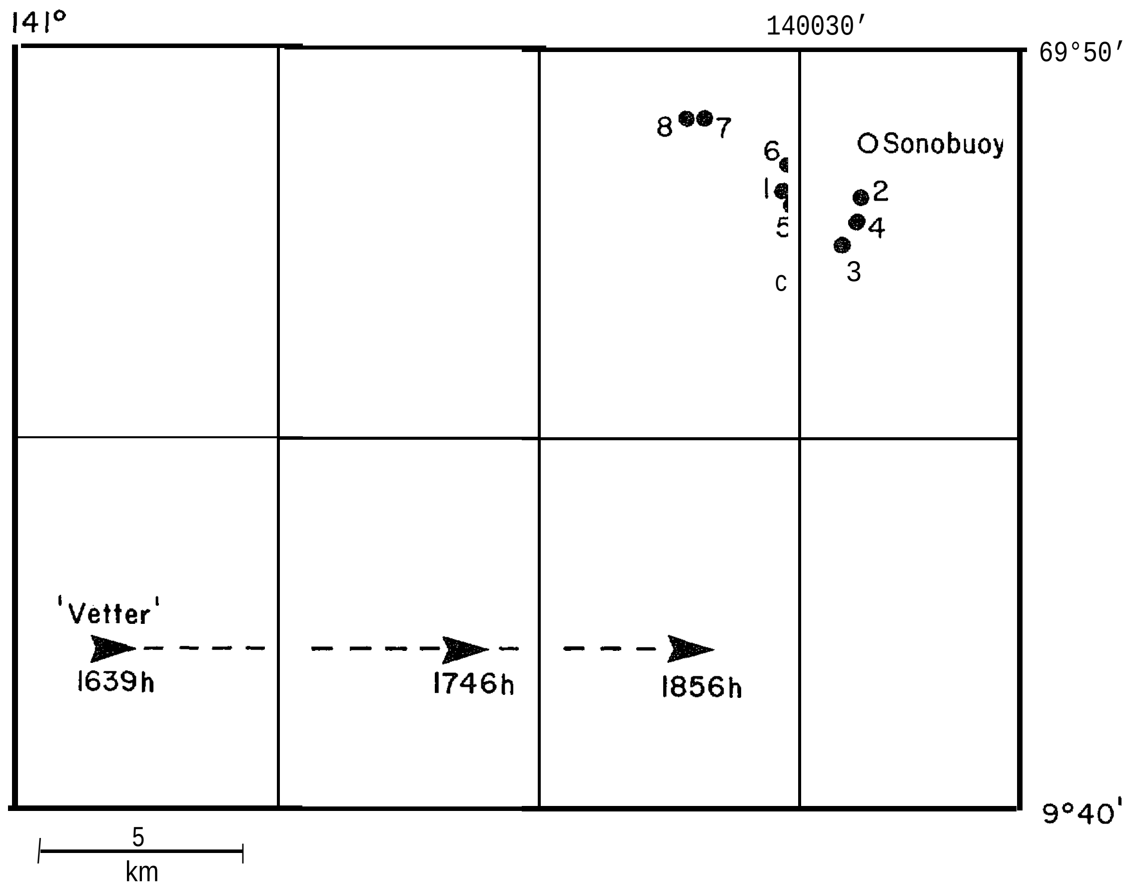

Fig. 2. Positions and movements of bowheads and the seismic vessel 'E.O. Vetter' during observations on 14 September 1981.

Bowheads did not orient directly away from the seismic vessel as it approached at an angle from 19 to 13 km away. However, a weak avoidance reaction may have occurred. Initially the whales moved slowly SE as the vessel approached from the SW (Fig. 2). When the ship was closer and SSW of the whales, the whales turned and moved slowly NW, roughly contrary to the eastward path of the vessel, although with an 'away' component as well. Movements of the bowheads resembled those during a seismic experiment in the eastern Beaufort Sea on 16 Aug 1984 (Richardson et al. 1985c). In the latter experiment, whales initially oriented away from the vessel after it began firing its airguns 7.5 km away. Later they oriented either perpendicularly away from its track, or parallel and contrary to its track. During the 16 Aug 1984 experiment, as during the 14 Sept 1981 observations, the whales moved at only slow to moderate speed as they oriented away or contrary to the vessel's track. There is no proof that the whales seen on 14 Sept 1981 were avoiding the vessel. However, it is interesting that, on both 14 Sept 1981 and 16 Aug 1984, they first moved roughly away from the approaching vessel, and then turned and moved partly contrary to and partly away from its track.

Bowhead sounds were recorded throughout the observation period. These sounds sometimes overlapped with the seismic pulses as received at the sonobuoys. However, because of the finite transmission speed of sounds in water, we do not know whether bowheads actually called at the same instant as they received seismic pulses. The bowhead sounds consisted of the usual types, including low-frequency moans, 'purring' sounds, and an occasional higher-frequency screech.

Seven surfacings by the female bowhead with accompanying calf averaged 2.41 ± s.d. 1.31 min in duration (range 0.83 - 4.75 rein). Three surfacings by other whales were 1.25, 1.67 and 2.83 min in duration. The overall average was 2.26 ± 1.16 rein, n=10 (Table 3A). Four dives by the maternal female averaged 13.58 ± 2.02 min (range 11.67 - 16.08 rein, Table 3B). With the exception of the longest surface time, 4.75 rein, the surface and dive times recorded on this date were well within the ranges for whales in the absence of seismic noise (Table 3). Surface times exceeding 4.75 minhave been observed during other studies of bowheads. Hence, there is no reason to believe that the 4.75 min surfacing on this date was related to the occurrence of seismic noise.

17 September 1981

On 17 September, we flew from Deadhorse eastward near the 20 m contour to Herschel Island (139°10'W) and return. At least 11 bowheads were found near the Alaska-Yukon border; sea state was 2-3 and ice cover was 1/10. Aircraft altitude was at least 457 m a.s.l. for most observations.

A sonobuoy detected both bowhead sounds and seismic pulses. The vessels responsible for these pulses are not known. The closest seismic vessel in Alaskan waters was 'GSI Mariner', which was operating at least 90 km to the northwest. Sharp pulses of medium intensity, each followed by an 'echo', were received throughout the observations. These sounds probably came from a vessel considerably less than 90 km away, in Canadian waters. In addition, a second and apparently more distant boat began shooting near the end of observations. Each received pulse from that vessel was also followed by an 'echo'. The second vessel may have been 'GSI Mariner', although this is uncertain.

The whales included a group of four socializing animals plus several other individuals within 1 km. The socializing whales rubbed against one another, sometimes with flippers out of the water. They created a conspicuous disturbance of the water surface. Surface and dive times were quite variable. The other individual whales outside the socializing group were apparently feeding in the water column. The whales seemed to call only when on the surface or just before they surfaced.

Bowhead Behavior With vs. Without Seismic Noise

The general activities of bowheads observed on three occasions in the presence of noise pulses from distant seismic vessels were typical of those observed in other situations. Feeding in the water column seemed to be occurring on each of the occasions when the whales were exposed to seismic impulses. Other activities observed in the presence of seismic noise included slow travel, calf play and little net movement, and active socializing (Table

1). All of these activities except calf play were noticed in the absence of seismic noise (Table 1). All of these activities, including calf play, have been observed during other studies of presumably undisturbed bowheads studied in late August and September (Reeves et al. 1983, 1984; Ljungblad et al. 1984b; Würsig et al. 1985a,b).

Bowhead calls were detected on each of the three days when the whales were exposed to seismic pulses, and on six of the seven days when no seismic pulses were detectable. Although no detailed analysis of bowhead calls was done as part of this project, there were no obvious differences in the types or characteristics of the calls in the presence and absence of seismic noise.

The surface times in the presence and absence of seismic noise were not significantly different (2.30 $\pm$ s.d. 1.54 min vs. 1.82 $\pm$ 0.94 rein, respectively; $t=1.62$, $df=68$, $p>0.1$). Similarly, durations of dives in the presence and absence of seismic noise were similar (10.65 $\pm$ 3.75 min vs. 13.31 $\pm$ 6.81 rein, respectively; Mann-Whitney $U = 78.5$; $p>0.1$). These comparisons include all data listed in Table 3. The observation aircraft had to circle at altitudes below 457 m on 5 of 6 dates with no seismic noise, but circled above 457 m on all three dates with seismic noise (Table 1). More detailed analysis is not warranted, given the possibility of aircraft disturbance on most dates without seismic noise, and the generally small sample sizes.

Based on observations in Alaskan waters in the autumn of 1981, we found no evidence of differences in behavior in the presence and absence of seismic noise. However, the observations were limited, and do not prove that bowheads are unaffected by seismic noise.

DISCUSSION

Bowhead Behavior in Relation to Aircraft

The possible effects of the observation aircraft on bowhead behavior are relevant here, given that many observations were obtained when the aircraft was circling below 457 m (1500 ft) above sea level (a.s.l.). Studies in the eastern Beaufort Sea in summer suggest that 457 m a.s.l. is the lowest altitude at which an observation aircraft can circle with reasonable assurance that bowheads are undisturbed (Richardson et al. 1985a,b). Cloud ceiling permitting, a minimum altitude of 457 m has been adopted for observations in Alaskan waters (this study; Reeves et al. 1983; Ljungblad et al. 1984b). Unfortunately, in the 1981 study, low clouds often prevented us from flying at ≥ 457 m. Comparisons are further complicated by the fact that all observations with seismic noise were from altitudes above 457 m, whereas most observations without seismic noise were from <457 m (Tables 1, 3).

Bowheads in Alaskan waters during autumn sometimes react to a turbine-powered Goose aircraft (Ljungblad et al. 1983, 1984a). Some quiescent bowheads begin to move, respire, or dive. Swimming bowheads sometimes change speed or direction, tail slap, congregate into a compact group, or dive. These types of apparent reactions have occasionally been noted when the aircraft was as high as 600 m altitude (Ljungblad et al. 1984a). In the eastern (Canadian) Beaufort Sea in summer, similar reactions to an Islander aircraft have been noticed, especially when the aircraft was below 457 m altitude (Richardson et al. 1985b,c). Such reactions were infrequent when the Islander was at altitude 457 m, and virtually absent when it was at 610 m. In summer, hasty dives are the most common apparent response to an aircraft (Richardson et al. 1985c).

On two dates during this study in 1981, we observed behavior that we interpreted as a reaction to the Goose aircraft. On 28 September, we twice suspected that dives were in response to the aircraft (altitude 183 m). Similarly, on 29 September, three whales dove in apparent response to the aircraft at 305 m.

Much subjective judgement is involved in interpreting whether bowheads overflown by an aircraft do or do not react. Occasionally the behavior is sufficiently abrupt and uncharacteristic to be readily interpretable as a disturbance response. However, on many occasions there is considerable doubt whether or not a dive or turn was in response to the aircraft. Bowheads sometimes show no conspicuous reaction to an aircraft circling at an altitude of 305 m, especially when they actively engaged in social interactions or feeding (Richardson et al. 1985c).

Even when no conspicuous reaction is apparent, behavior is sometimes affected subtly by an observation aircraft. Intervals between successive respirations tend to be shorter when an Islander circles at 305 m a.s.l. than when the same aircraft circles the same whales at 457-6Io m (Richardson et al. 1985b,c). Durations of surfacings and dives are not altered appreciably when an observation aircraft descends from 457-610 m to 305 m. However, caution is necessary in interpreting any behavioral observations from altitudes below 457 m, given the subjective observations reviewed above, plus the fact that average blow intervals become significantly shorter when the aircraft descends to 305 m.

Bowhead Behavior in Summer and Autumn

Bowheads have been observed from circling aircraft during late summer in the Canadian Beaufort Sea, and during late summer and early autumn in the Alaskan Beaufort Sea. Activities during summer and autumn were compared by Würsig et al. (1985a,b) and Ljungblad et al. (1984b). Their comparisons consider observations from 1980–84 and 1979–83, respectively. Bowhead activities are qualitatively similar in the two periods and areas. Bowheads sometimes feed at the surface, in the water column, and near the bottom in the Alaskan Beaufort Sea in autumn as well as the Canadian Beaufort Sea in summer. Feeding in the Alaskan Beaufort Sea continues into early October in some years (Ljungblad et al. 1983, 1984a). Mother/calf interactions, other social interactions, and aerial activity (breaching, tail and flipper slapping) occur in both areas and seasons. In both situations, motion can range from nil to strongly directed travel, and activities of bowheads spread over many km2 are often partially synchronized. Call types are very similar in the two areas (Ljungblad et al. 1982b, 1983, 1984a; Würsig et al. 1985b).

Although the repertoire of activities is similar in the two areas and periods, relative frequencies of some activities vary. Social interactions seem to become progressively less frequent from spring through summer to autumn (Ljungblad et al. 1984b; Würsig et al. 1985b). Westward-directed travel becomes more frequent as the season progresses, both the Canadian Beaufort Sea (Renaud and Davis 1981; McLaren and Davis 1984) and in Alaska (Ljungblad et al. 1984a). Feeding may be less frequent in the Alaskan Beaufort Sea in autumn than in Canadian waters in summer, especially in years with heavy ice in Alaskan waters in September (Ljungblad et al. 1984a).

Our results from 1981 were consistent with the above generalizations, in part because the 1981 results were taken into account by Würsig et al. and Ljungblad et al. in deriving those generalizations. Feeding, socializing, mother/calf interactions, and travel were all observed. Feeding was apparently still in progress in Alaskan waters as late as 5 October in 1981, which was a relatively light ice year. In general, results from 1981 and other recent years show that the activities of bowhead whales in the Canadian and Alaskan parts of the Beaufort Sea during late summer and early autumn are similar. Activities in summer are not restricted to feeding, and activities in early autumn are not restricted to migration.

In both areas and periods, bowheads show similar patterns of short surfacings alternating with longer dives. However, surfacings and dives tended to be longer in Alaskan waters (Table 4). The overall mean duration of surfacings was significantly greater in Alaskan than Canadian waters (1.43 vs. 1.19 rein, $t=2.92$, $p<0.01$). There was much variability in both areas, and much overlap. In 1 of 3 years (1982), the trend was reversed (Table 4). Similarly, the overall mean duration of dives was over twice as long in Alaskan than Canadian waters (9.18 vs. 4.42 rein). Again, however, there was much overlap, and in 1982 the trend was reversed. Durations of surfacings and dives are known to vary with year, activity of whales, and water depth within the Canadian Beaufort Sea (Würsig et al. 1984, 1985b). These variations are at least as great as those between the Alaskan and

Table 4. Durations of surfacings and dives by bowhead whales in the absence of potential disturbance, with the possible exception of aircraft disturbance in Alaska[a]. Calves are excluded.

	Canada[b]			Alaska[a]		
	Mean	s.d.	n	Mean	s.d.	n
Duration of Surfacing (rein)						
1980	1.25	0.723	94			
1981	1.06	0.764	204	1.82	0.94	42
1982	2.05	1.320	70	1.41	0.57	36
1983	1.05	1.484	248	1.33	1.10	168
1984	1.10	0.559	99	–		
Al 1	1.19	1.137	715	1.43	1.03	246
Duration of Dive (ruin)						
1980	2.25	3.549	25			
1981	3.80	4.986	80	13.31	6.81	20
1982	12.08	9.153	51	10.27	5.55	36
1983	1.88	2.357	140	7.11	5.94	59
1984	6.27	7.195	37			
All	4.42	6.319	333	9.18	6.38	115

[a] 'Alaskan' data are from this study, Reeves et al. (1984) and Ljungblad et al. (1984b). A few of these data came from the Canadian Beaufort Sea.
[b] Canadian data are from Würsig et al. (1985b).

Canadian results listed in Table 4.

We conclude that behavior of bowheads in the Canadian Beaufort Sea in late summer is quite similar to that in the Alaskan Beaufort Sea in late summer and autumn. However, there are subtle quantitative differences in the relative frequencies of different activities, such as feeding, socializing and travel. There may also be subtle differences in average durations of surfacings and dives, although the reversal of this trend in 1 of 3 years renders this point questionable.

Bowhead Behavior in Relation to Seismic Exploration

In 1981, we found no definite reactions of bowhead whales to noise from distant seismic vessels, although the whales observed on 14 September 1981 may have been slowly avoiding the vessel. These results were consistent with those of other recent studies of bowheads in the Alaskan and Canadian Beaufort Sea, in which bowheads often seemed to tolerate strong seismic impulses, and reactions to seismic vessels were demonstrated conclusively only when the vessel was less than 7.5 km away (Richardson et al. 1985c; Ljungblad et al. in prep.). In 1981, the seismic vessel was at least 13 km away during the three observations. (On 2 of 3 days, the distance was unknown, but undoubtedly >13 km given the low received levels of the seismic impulses and the fact that ship was not seen during behavioral observations.)

In the 1981 study, there was no evidence of reduced surface or dive durations in the presence of seismic noise ($p>0.1$ in both cases; see Results), and no cases of 'huddling' were seen (cf. Reeves et al. 1983, 1984). In some other opportunistic observations of bowheads exposed to noise impulses from distant seismic vessels, there have been subtle indications of reduced durations of surfacings and dives, and reduced numbers of blows per surfacing (Reeves et al. 1983, 1984; Ljungblad et al. 1984b; Richardson et al. 1985b,c). However, the trends have been weak and inconsistent, with much overlap and some seemingly contrary cases. Multivariate analysis of the summer observations in the Canadian Beaufort Sea has shown that the weak trends might be attributable to factors other than seismic noise (Richardson et al. 1985c). However, these trends in the presence of noise from distant seismic vessels are nonetheless noteworthy, because they are consistent in direction with the much stronger and clearer trends found on four occasions when seismic vessels approached bowheads closely (Ljungblad et al. in prep.).

In summary, the present study provided additional evidence that bowheads often engage in seemingly normal activities in the presence of strong seismic impulses. Although there is no proof from this or other work that bowheads more than a few kilometres from seismic vessels react to the noise impulses, there is some evidence consistent with the possibility of subtle effects on surfacing - respiration - dive cycles at greater ranges (Richardson et al. 1985b,c), and of weak avoidance reactions at longer ranges (this study, 14 Sept 1981 case). Such reactions are not particularly surprising, given that high-energy seismic vessels ensonify the water with strong noise impulses out to distances of tens of kilometres (Greene 1982-85; Malme et al. 1983). It is not known whether the subtle behavioral reactions that may occur at ranges exceeding a few kilometres are in any way harmful to bowheads.

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